ON THE ABSORPTION COEFFICIENTS AND ENERGY SPECTRA OF GAMMA-RAYS FROM RA (B+C) UNDER THICK LAYERS OF Pb ABSORBER

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ABSTRACT The absorption coefficients and energy spectra of gamma-rays from 500 mc of Ra in equilibrium were measured under thick layers of Pb from 18.5 to 27.5 cm with a sodium iodide (thallium activated) crystal in combination with a linear amplifier and differential energy discriminator. The absorption coefficient measured with absorber of very small lateral dimensions and for the gamma-rays of highest energy, *e.g.*, 2.494 ± 0.073 Mev emitted by radium is about 8% less than the theoretical value. But when a strong and wide beam is used by placing the Ra source immediately below the absorber then the measured absorption coefficients show anomalous variations as previously reported by the author. The energy spectra measured under 18.5 cm and 20.5 cm of Pb absorber show three peaks at about 2.494 ± 0.073, 2.220 ± 0.065 and at 1.776 ± 0.052 Mev and the energy spectra under 23.5 cm shows in addition to these three peaks indications of another peak at 1.469 ± 0.043 Mev.

INTRODUCTION

A few years past the author (Senchaudhury, 1948, 51, 54) reported some anomalous variations in the experimental values of absorption coefficients of gamma-rays from radon in equilibrium under thick layers of Pb absorber and it was suspected that these might be due to some penetrating radiation of secondary origin. But the author's experiments were repeated by Dixon and Whyte (1952) in Canada and by Clay and co-workers (1952) in Amsterdam with conflicting results. Dixon and Whyte carefully did the experiment apparently under the same conditions as the author and obtained a constant absorption coefficient under 13 to 26 cm of Pb, whereas Clay with an ionisation chamber obtained the absorption coefficients monotonously decreasing to values far below the theoretical minimum values. Now a careful study of the paper by Dixon and Whyte showed that one of the main differences between their and author's previous experimental arrangements was that they used a highly canalised beam with a canal of depth 30 cm, whereas in author's experiments a radon capsule of length about 3 cm was placed in a cavity of only about 4 cm depth. This means a great difference, firstly although they have used a radium source of one curie strength, the intensity of the radiation on the absorber had been reduced by a factor of $1/30^2 = 1/900$, and the effective strength of the radiation was about 1 mc only. They used 5 cm thick Pb shielding on the sides of the detector, whereas the author used only 1 cm thick Pb shield. In all the previous experiments the absorption coefficients for the integral beam only have been measured that is the average absorption coefficient of the highly heterogeneous beam of gamma-rays emitted by Ra and therefore the comparison of the experimental values with those of the theoretically calculated values are meaningless except that the absorption coefficients should not be less than the theoretical minimum values of about 0.47 cm^{-1} in Pb. There has also been some controversy about the energy spectra of gamma-rays from Ra (B+C) and Whyte (1952) only indirectly inferred the energy spectra from transmission curves under thick layers of Pb.

In view of all these the author was waiting for a suitable opportunity to repeat the former experiments and also to visualise directly the energy spectra under thick layer of Pb. absorber. By the courtesy of Prof. Lauterjung of the Institut für Physik Im Max-Planck-Institut fur Modicinische Forschung at Heidelberg it has been possible for the author to repeat the experiments more carefully during a study leave in West Germany. Several sets of measurements were made under different experimental arrangements with the two-fold objects, firstly, to investigate the anomalous variations in absorption coefficients under certain experimental conditions and the nature of secondary radiations producing such localised variation and secondly, to see how far the experimental values can be brought in agreement with the theoretically calculated values by eleminating all secondary radiation and measuring with nearly monochromatic radiation only.

EXPERIMENTAL ARRANGEMENTS

In these investigations a sodium-iodide (thallium activated) Harsha crystal of diameter and depth 5 cm with a linear amplifier and differential discriminator has been used as the detector and as a spectrometer. The linear amplifier used is model 218 and the differential discriminator is a single channel 510 pulse-height analyser of the Atomic Instrument Co, with resolving time 0.8μ sec. and 10μsec. respectively. The recorder was a 1000 scaler of Tracer Lab of resolving time 1μsec. The photomultiplier used was R.C.A. 6342 and the high voltage supplied to its cathode was from a model 312 super stable power supply. The differential discriminator was calibrated by the peak of Cs^{137} gamma-rays and the constancy of the linear scale was tested almost every time before and after each experiment. The strength of the Ra source was 500 mc. Mainly three sets of experimental arrangements have been used in these investigations e.g.

1. (a) Detector unshielded and the beam not canalised,
   (b) Same as (a) but with sides shielded detector,
2. Canalised beam and sides shielded detector,

3. Same as 2, but the lateral dimensions of the absorber used are very small.

The different experimental arrangements are shown in the figure 1. The experimental arrangements 1(a) are similar to the previous arrangements of

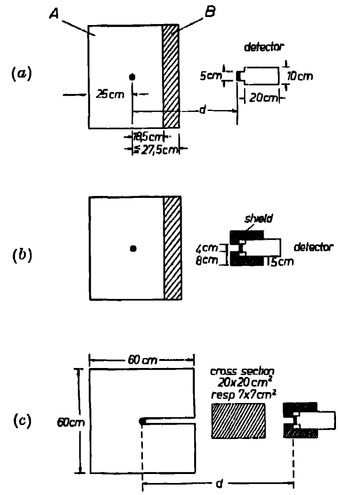

Fig. 1.—Experimental arrangements.

(*a*) Beam not canalised. Detector unshielded.

(*b*) As in (*a*) but detector shielded.

(*c*) Beam canalised, detector shielded and with two different lateral dimensions of the absorber.

the author except 30 cm Pb, shielding all but the front side of the Ra source to prevent any radiation escaping to the room other than through the front absorber. Under these conditions it was found that the counting rate by the detector reduced to that of the background when about 33 cm Pb absorber was used in the front. The detector sides were not shielded by Pb as preliminary experiments showed that such heavy shield appreciably reduce the absorption coefficients by scattering back to the detector some of the radiation scattered by the absorber. Further, any remaining scattered radiation by wall reflection etc., which are of very low energy, were cut off by the energy discriminator except for the total integral beam. The arrangements (b) are similar to (a) except 5 cm thick Pb shielded the sides of the detector. The experimental arrangements (c) with a canalised beam of canal depth 30 cm are exactly similar to that of Dixon and Whyte. Absorbers of two lateral dimensions, e.g., 20 cm × 20 cm and 7 cm × 7 cm were used.

EXPERIMENTAL RESULTS

The counting rates, subtracting the background with different thickness of Pb absorber and with different energy cut-offs under the experimental arrangements (a), are shown in logarithmic scale in the figure 2. The curves are represented by the number 1, and the size of the points represents the statistical error when it is not shown otherwise. The measured absorption coefficients for three different distances of the detector from the Ra source, e.g., 75 cm, 64 cm and 49 cm and for the integral beam of energy greater than 1.029 Mev. are shown in the figure 3 together with the mean curve under different thicknesses of Pb absorber. The absorption coefficients were measured from 18.5 cm to 27.5 cm Pb absorber at the interval of 1 cm only. It may be observed that

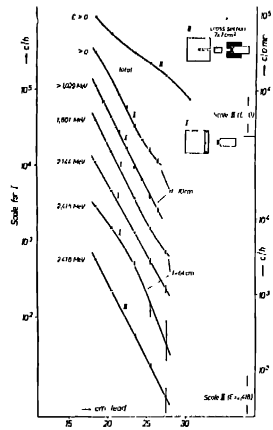

Fig. 2.—Counting rates from source radiations for different energy cut-off.
Curves I · Beam not canalised, detector unshielded (Expt. Ia)
Curves II : Beam canalised, detector shielded, absorber cross-sections 7×7 cm² arrangements according to Fig. 1(c).

in all the three curves the absorption coefficient steadily decreases to a minimum under about 21.5 to 22.5 cm Pb followed by a steady rise to a maximum under 23.5 cm Pb and a sharp fall again to a value much below the theoretically expected and the minimum value under 24 5 cm. In each curve a new rise again under 25.5 cm is indicated. The theoretically expected value is represented by the dotted line and it is nearer to the peak value under 23.5 cm Pb.. The measured absorption coefficients for the integral beam of all energy also shows exactly similar variations. The conditions of these measurements are nearly similar to those of the previous measurements by the author. In the previous results there was a steady decrease of the measured absorption coefficients after 20 cm of Pb absorber to a minimum between 23 and 25 cm with a rise again after 25 cm. But in the previous measurements Pb absorber at the interval of 2 cm or more were used and probably therefore the additional increase under

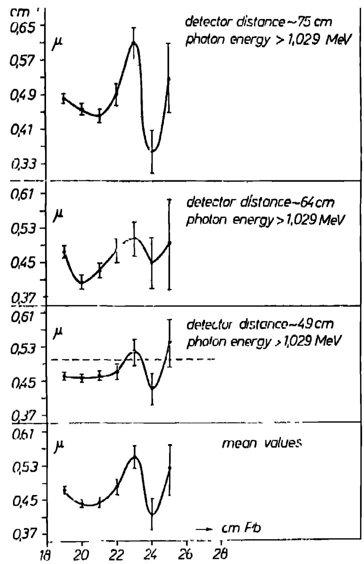

Fig. 3 —Absorption coefficients for the integral beam with $E > 1,029$ Mev under different absorber thickness measured at three different distances between the source and the detector. Beam not canalised, detector unshielded. Arrangements 1a Lower curve: Mean of three curves for different distances.

23.5 cm indicated by the present experiment, was not detected. But the measurements with the arrangements (b) shielding the sides of the detector by 5 cm thick Pb show that for the integral beam and for the integral beam of energy greater than 1 029 Mev, the absorption coefficients steadily decrease to a value below the theoretical minimum value after 23.5 cm of Pb absorber.

The experimental arrangements (c) are exactly similar to those of Dixon and Whyte (1952) and the measured absorption coefficients for the integral beam of all energy and for energy greater than 1.029 Mev. measured with Pb absorber of dimension 20 cm by 20 cm are also similar to those obtained by these workers. There are no anomalous variations and the measured absorption coefficients are nearly constant and equal to theoretically expected values. But the measured absorption coefficients for higher energy cut-offs and nearly monochromatic radiations are always smaller than the theoretical values. In the final measurements with the arrangements (c) the absorbers of lateral dimension 7 cm $\times$ 7 cm were used and the absorption coefficients were measured for the integral beam of all energy and for the photons of energy 2.494 ± 0.073 Mev, which the energy spectra measurements showed to be the highest energy component of gamma-rays from Ra (B+C) The log intensity curves are shown in the figure 2 with the curves marked III. The measured absorption coefficients for the integral beam are much smaller than the theoretical minimum values similar to those obtained by Clay (1952) and reduce to as low as 0.17 cm^{-1} under 23.5/cm Pb absorber. But it was observed that the counting rate by the detector could not be reduced to that of the background even after 40 cm of Pb absorber. It is therefore obvious that such low values of absorption coefficients are due to a considerable fraction of the scattered radiation from the absorber which is scattered back to the detector by the large Pb. shield surrounding its sides. For the Compton scattering is maximum in the forward direction and as the lateral dimension of the Pb absorber is very small, these scattered radiations are not further reabsorbed as the successive thickness of Pb absorber is increased. When the measurements were made for gamma-rays of highest energy 2.494 ± 0.073 Mev. only cutting-off all scattered radiations of lower energy by the discriminator with narrow channel width, the measured absorption coefficient was about 0.455 cm^{-1} which is only about 8% less than the theoretical value.

ENERGY SPECTRA

For the experimental arrangements (a) the energy spectra of gamma-rays from Ra (B+C) were measured under 18.5 cm and 23.5 cm Pb absorber together with that of the background under 23.5 cm The measured spectra are represented in the figure 4, one volt pulse height is equivalent to $0.0342 \pm .001$ Mev. The energy spectra are shown for gamma-rays of energy greater than about one Mev. only for the energy spectra under 1 Mev show no peak but a continuous energy distribution. The energy spectra under 18.5 cm curve *A* show peaks at 1.77 ± 0.065, 2.22 ± 0.09 and 2.39 ± 0.07 Mev The energy spectra under 23.5 cm curve (c) shows in addition to three peaks a new peak at 1.469 ± 0.043 Mev. But slightly displaced towards higher energy there is also a peak in the background curve *B* at 1.537 ± 0.045 Mev. The limit of error to each peak energy is the constant error of calibration and do not affect the relative position of the peaks. The constancy of the linear scale of the amplifier was tested by the constancy of position of Cs^{137} peak almost after every experiment.

For the experimental arrangements (c) the energy spectra were measured under 20.5 cm and 23.5 cm Pb absorber with the background spectra under 23.5 cm. The energy spectra under 20.5 cm shows three peaks at 2.49 ± 0.073

Mev. 2.289±0.067 Mev. and at 1.7761±0.052 Mev. The energy spectra under 23.5 cm shows four peaks at 2 46±0.07 Mev, 2.280±0.06 Mev, 1.800±0.05 Mev and at 1.47±0.043 Mev. The peak at 2.49±0.07 Mev is very clear under this experimental arrangements though it was scarcely visible under the arrange-

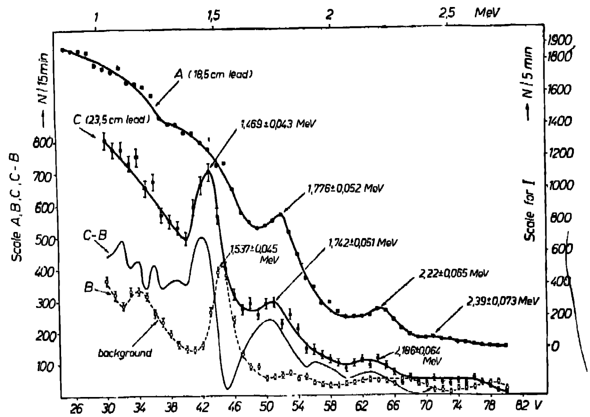

Fig. 4.—Energy spectra of the total radiation (source and background) under 18.5 and 23.5 cm Pb absorber (curve A and C).
Background without source radiation (curve B), curve (C-B) Photon spectra of the Ra source under 23.5 cm Pb absorber. Arrangements 1(a).

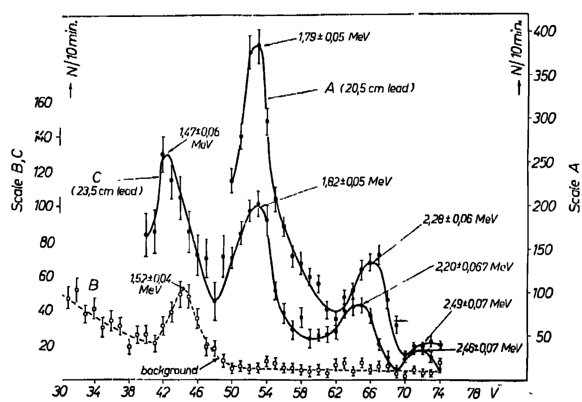

Fig. 5.—Energy spectra of the total radiation (source and background) under 20.05 cm (curve A) and under 23.5 cm Pb (curve C) together with the background (Curve B) Conditions : Beam canalised, detector shielded and absorber cross-sections 20×20 cm

ment (a). This peak was first reported by Lathyshev and co-workers (1947). Again the peak at 1.47 ± 0.043 Mev exactly coincides with that under the experimental arrangement (a) and there is also the background peak as in previous experiment at 1.537 ± 0.045 Mev. As the energy difference between these two peaks is very small it is natural to think that the peak with Ra source is simply the background peak shifted to lower energy due to increase in intensity with Ra source. To investigate this point the energy spectra of Cs^{137} gamma-rays were measured for different total intensities by changing the distance of the Cs^{137} source from the crystal detector and it was found that there was slight shift of the peak towards higher energy with the increase of the total intensity when the linear scale was calibrated at lower intensity. This is also expected from the slight decrease in sensitivity of the photo-cell cathode at higher intensity. The measured energy spectra of Ra gamma-rays under different thickness of Pb absorber also show that as the intensity is increased by decreasing the absorber thickness, there is slight shift towards higher energy of all the peaks except the new peak at 1.469 Mev which is at energy lower than its neighbour background peak. Also with the experimental arrangements (c) the total intensity was cut down by a factor of about 1/7 in comparison with that under (a) still the position of these two peaks remained exactly same Therefore, it is very unlikely that the peak with radium is the same peak ' he background.

DISCUSSIONS

Finally to summarise the results these investigations have shown that for the experimental arrangements with a wide and very strong incident beam on the absorber by placing 500 mc Ra immediately below it, the variations of absorption coefficients between 20.05 and 25.5 cm are anomalous as reported by the author previously. But the anomaly disappears when a highly canalised beam similar to that of Dixon and Whyte is used. Also when the absorption coefficients are measured for the gamma-rays of highest energy only cutting off all the secondary radiations of lower energy by the energy discriminator and using absorber of very small lateral dimension to prevent the production of appreciable secondaries by multiple scattering etc., the measured value is constant and only about 8% less than the theoretical value. It is, therefore, clear that the anomalies appearing under the experimental arrangements described above must be due to secondary radiations produced either by multiple scattering or these are produced locally in the anomalous region by some unknown process. But it is difficult to understand how multiple scattering which is a continuous process can produce such sharp localised increase and decrease in the absorption. Therefore the appearance of a new peak of energy 1.469 ± 0.043 Mev under 23.5 cm Pb may be significant It could, however, be still better decided if the energy spectra were measured in a laboratory where the neighbouring background peak due to radio-active contamination or cosmic-rays was absent. A careful search was also made with a BF_3 counter if any appreciable number of neutrons were emitted by the 500 mc Ra source due to interaction with light elements in glass container etc., but no extra count over the natural background was detected.

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